Observation of Dust in DIII-D During Normal Plasma Operation Using Rayleigh/Mie Scattering

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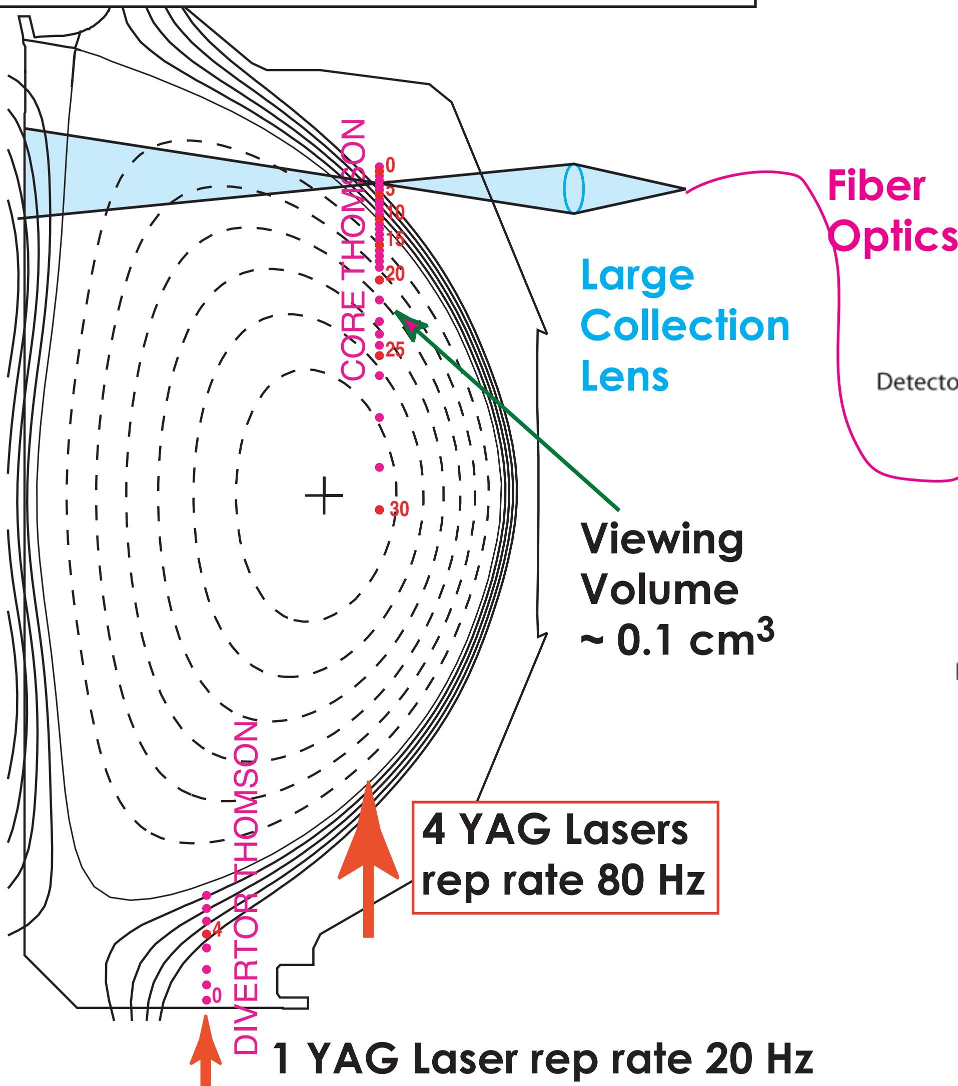
DIII-D NATIONAL FUSION FACILITY
GENERAL ATOMICS

Multiple Sources of Dust Exist in DIII-D

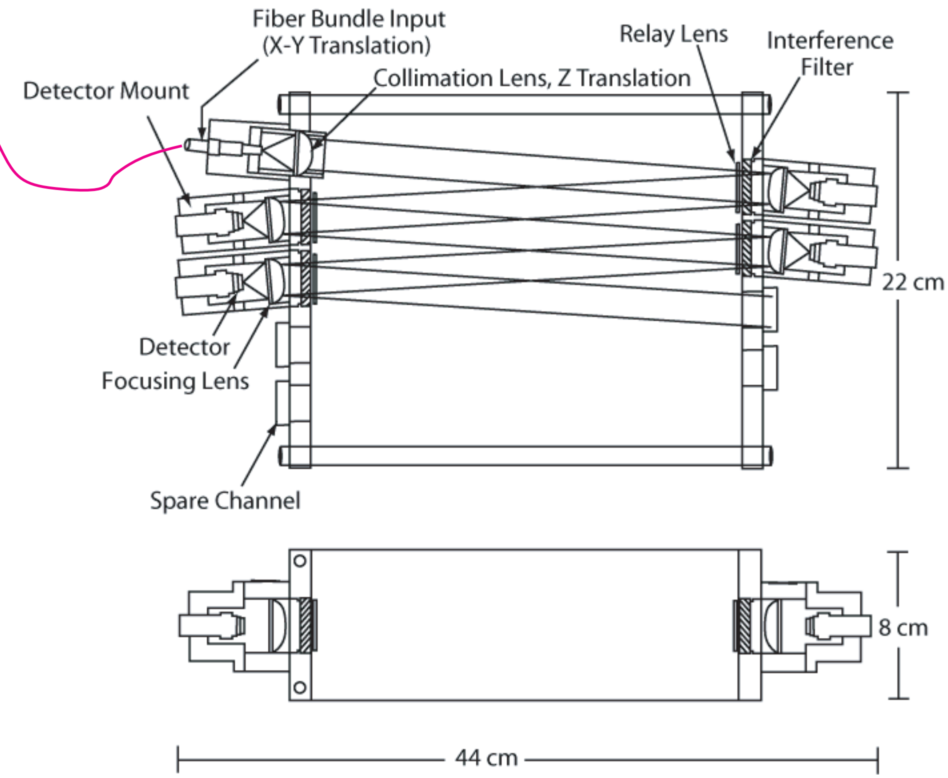
- **Flakes from redeposited C_xD_y films**
- **High Heat Flux Generation**
  - Leading edges and monopolar arcs
  - Thermal Stress Induced Fracture
  - Volume Condensation
- **Particles left over from entry vent activities**
- **Degradation of grafoil compliant layers under tiles**

DIII-D Thomson System Used to Detect Dust Particles

- **Thomson viewing locations**

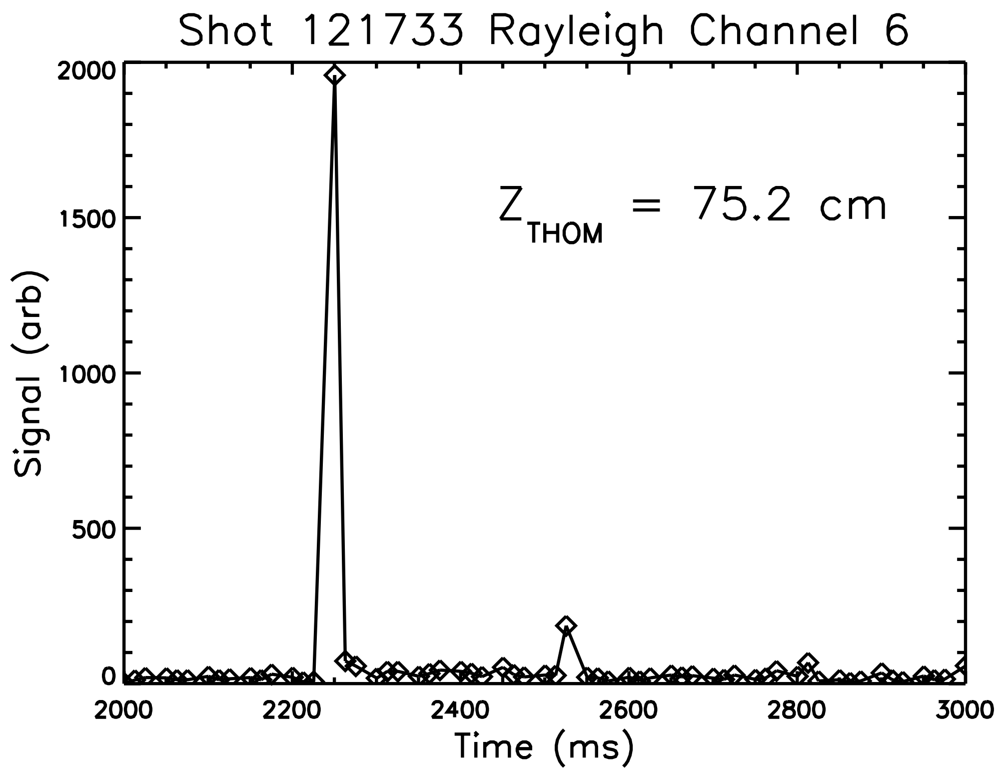


- **Polychromator at each location**
  - Rayleigh Channel Passes Laser Light at 1064 nm
  - Next Channel at 1062 nm has 10^{-2}-10^{-4} extinction at laser line
  - 4 more channels further blue shifted



Large Excursions Observed in Rayleigh Signal

- **Other causes of large excursions can be discriminated against.**
  - Bright Thermal/plasma light from far wall
    - Discriminated against by fast background subtraction
    - Would appear simultaneously in several spatial and λ channels
  - Scattered laser light from wall
    - Would appear simultaneously in several spatial channels
  - Neutrons, γ's, cosmic rays
    - Would appear uniformly in all channels



- **Observed during normal plasma operation**

Dust signatures found in search of existing Thomson data

- **Examined core and divertor data over ~700 discharges**
  - Search of 31 core channels: 1.5 x 10^5 laser pulses
  - 8 Divertor channels: 3.8 x 10^4 laser pulses

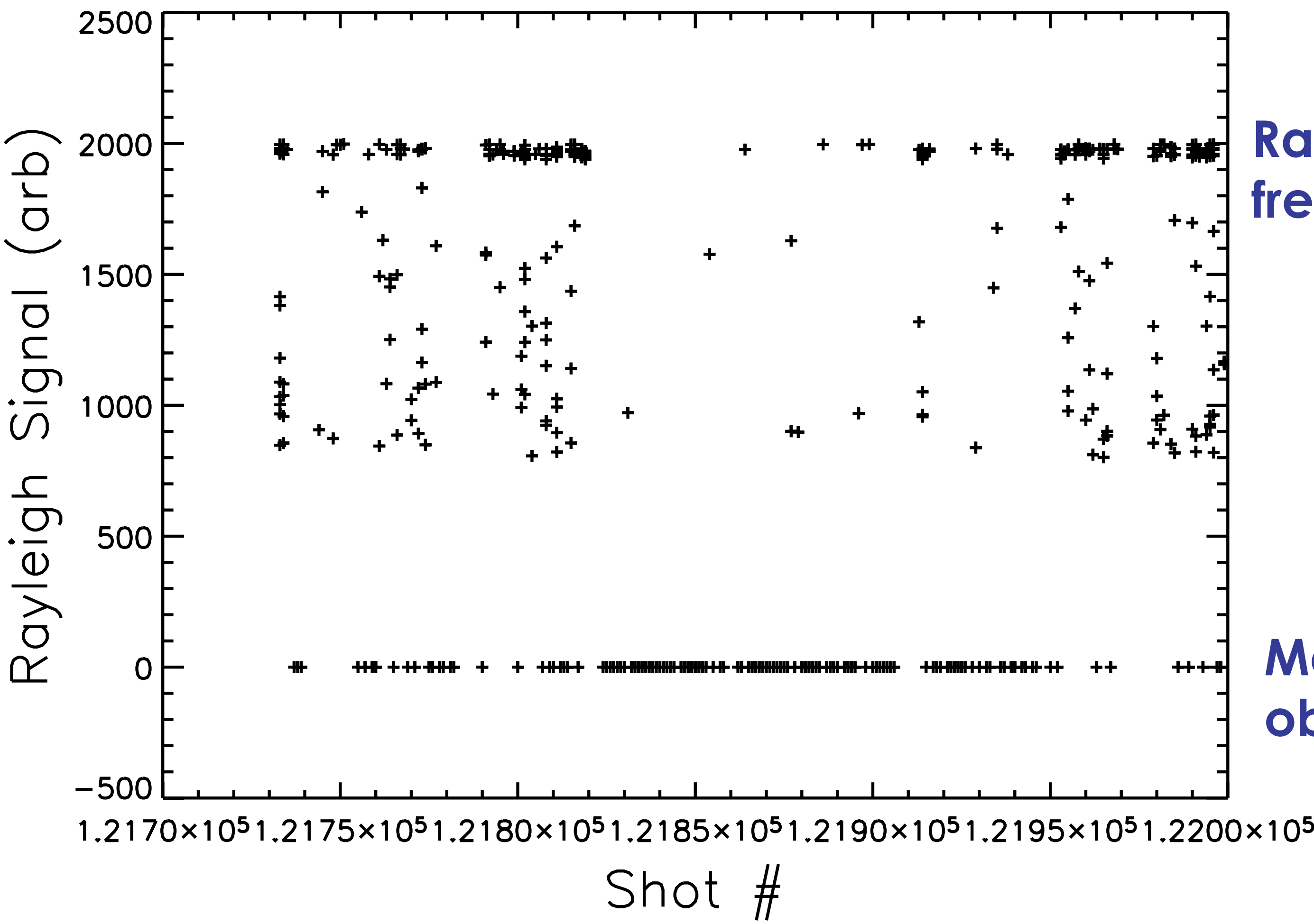
- **Search only when Ip > 0.9 MA, for at least 700 ms**
  - Require Rayleigh signal > 200 counts
  - Reject times with simultaneous excursion in more than 2 core (divertor) Thomson spatial channels
  - Reject times when neighboring times have large excursion in same spatial channel
  - Excursions are recorded for all λ channels

Search Statistics From Core Thomson shots 121733-121999

- **209 Shots with at least 700 ms at I_p > 900 kA.**
  - 124 Shots exhibited no dust signature

- **293 large events in Rayleigh channels selected**
  - 266 events in region of typical SOL (13 channels)
  - 27 events in region of confined plasma (18 channels)
  - 28 events in shifted λ channels (150 channels)
  - 26 times rejected due to excursions in multiple Rayleigh channels

Dust apparant in recent shots taken over a two week period

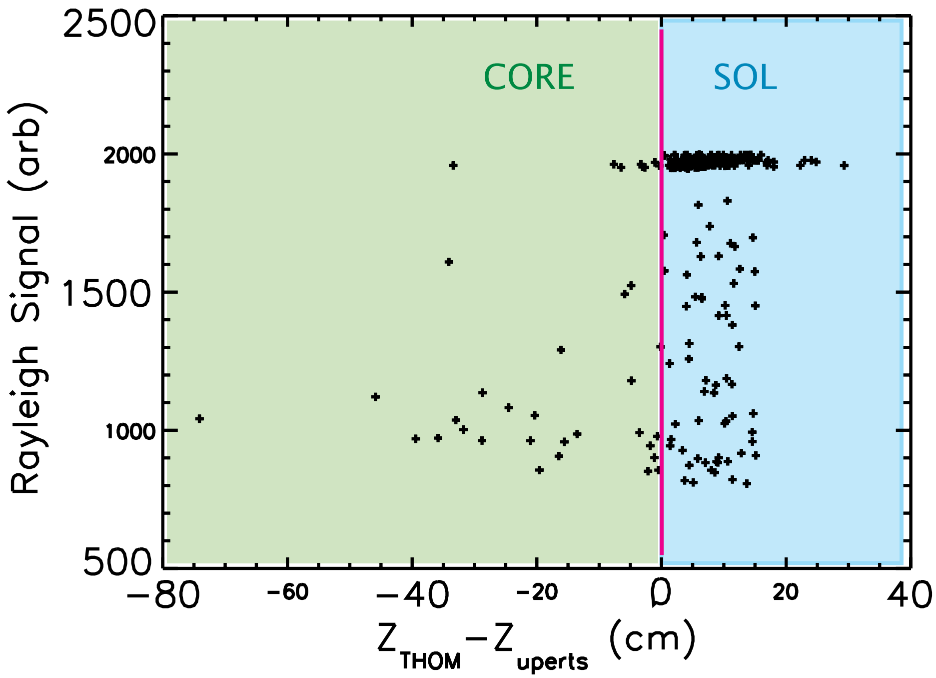


Rayleigh signal frequently saturates

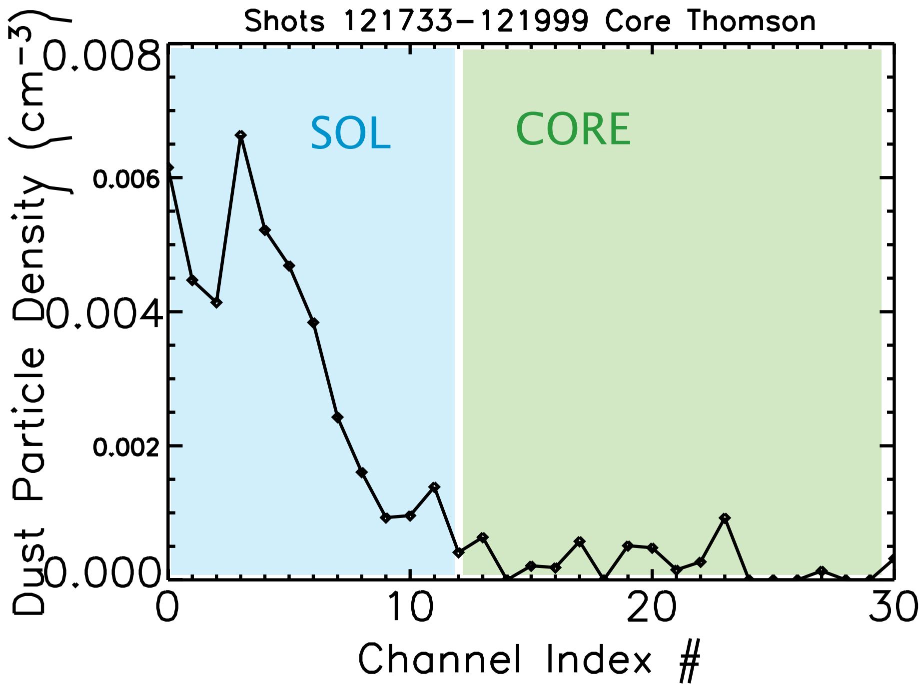
Many shots with no observed dust

Dust Density Falls from Wall to Separatrix

Dust Frequent in SOL but
Rare in the Core



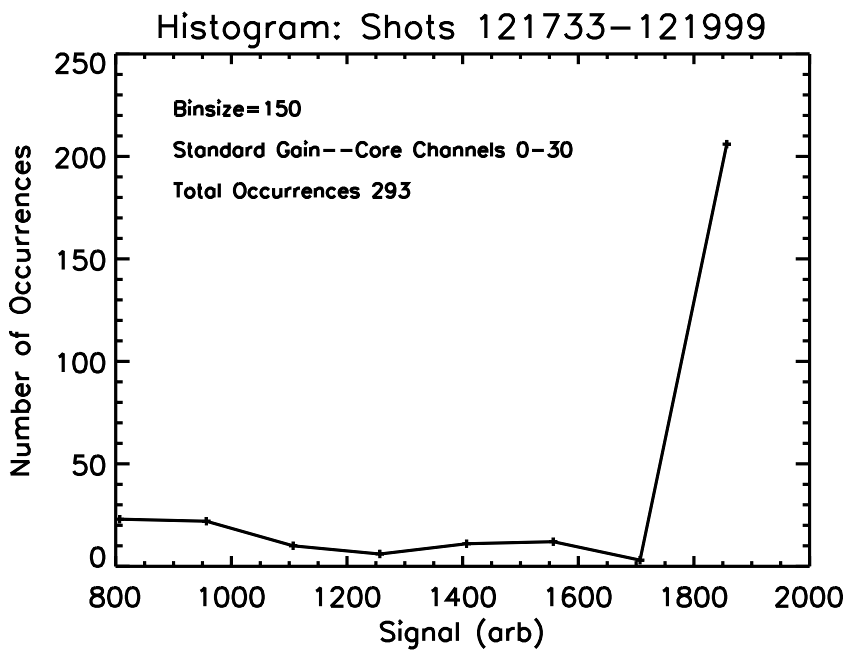
Particle Density vs
Thomson Channel Index



Time Averaged Dust density =
 # events/(viewing volume x # laser pulses)

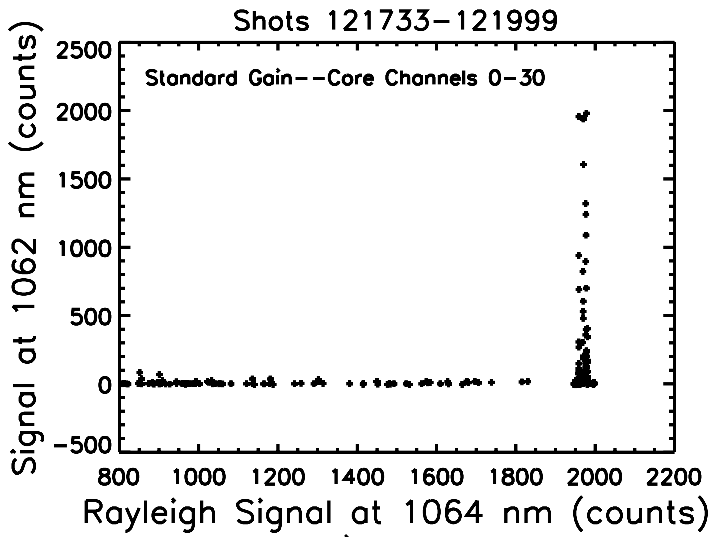
Rayleigh Signal Typically Saturated

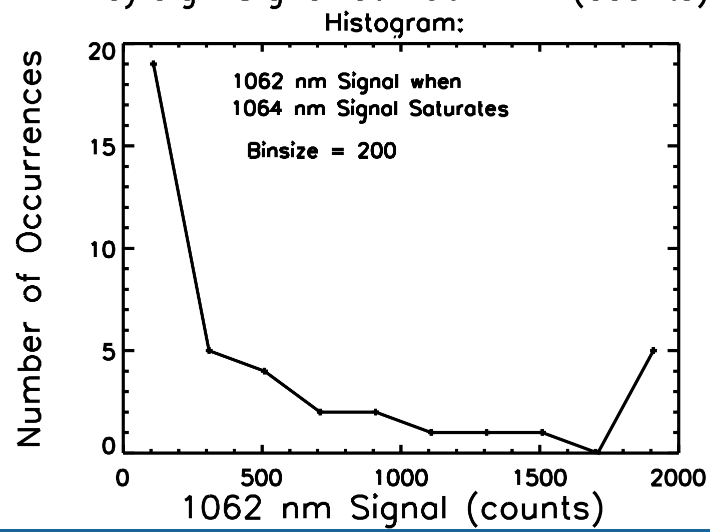
Rayleigh Channel 1064 nm



- 1062 Channel Attenuates YAG Laser Light by 10^{-4}

1062 nm Channel





Rough Estimate of Particle Size from Thomson Rayleigh Calibration

- **Rayleigh Scattering Cross Section, σ for conducting particle, radius a**

$$\sigma = 10\frac{\pi}{3}k^4a^6$$

$$k = 2\pi/\lambda$$

$$(a_{part}/a_{Argon})^6 = \frac{S_{part}}{S_{Argon}/N_{Argon}}$$

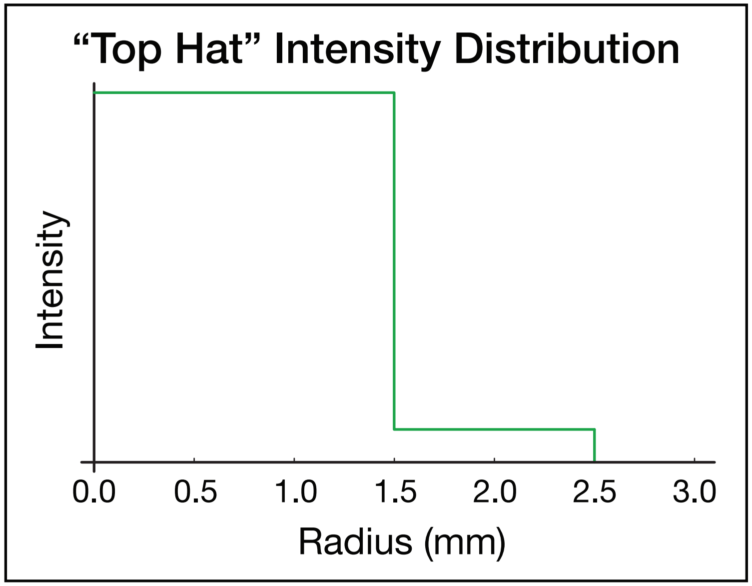
- S_{Argon} = Rayleigh Signal wiith N_{Argon} atoms in viewing volume
  - a_{Argon}, ~ 1.1 Å, obtained from measured σ_{Argon} from the literature

Modeling goals

- **Laser intensity is nonuniform over imaging volume, denying the existence of a one-to-one function from particle radius to detected signal size**
  - We can only take a particle radius [distribution] and predict a signal size [distribution]
- **As such, our method involves:**
  - Using an assumed particle radius distribution to predict a signal size distribution;
  - Calculating the fit error between the predicted and experimental signal size distributions; and
  - Adjusting parameters in the assumed particle radius distribution to minimize error in the predicted signal size distribution

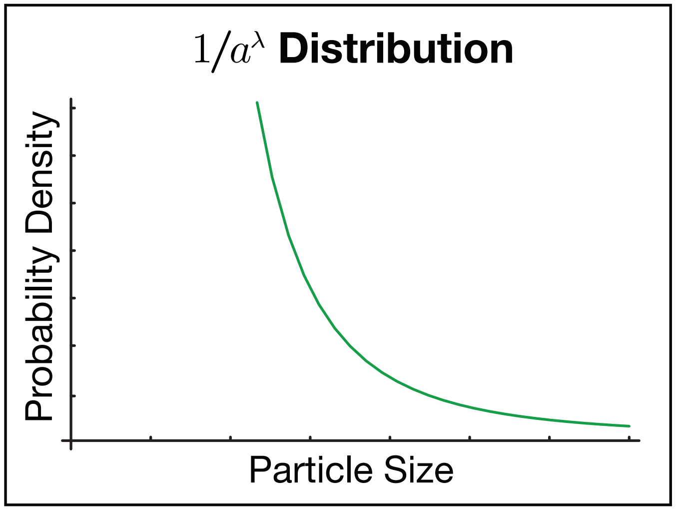
Model assumptions

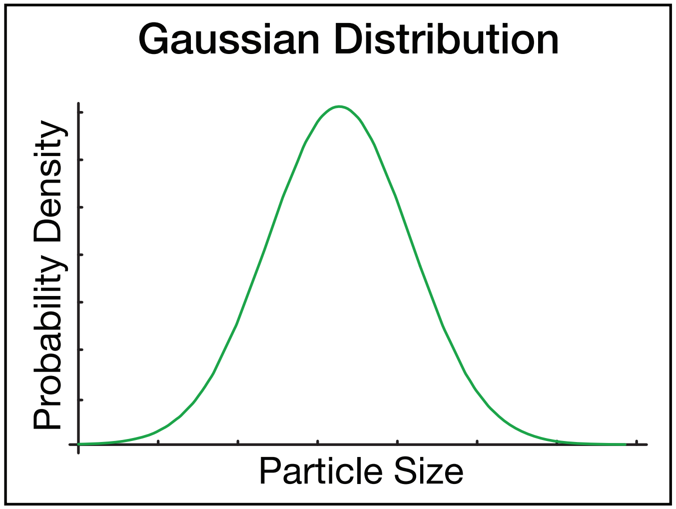
- **Rayleigh scattering formula holds**
  - In reality, only a good approximation if scattering particle radius is less than about 10% of wavelength of incident light
  - a < 106 nm, in this case
- **"Top hat" laser intensity distribution**
  - Our data suggests:
    - 95% of laser power within 1.5 mm radius
    - 5% in concentric ring of 2.5 mm outer radius
  - We use this "top hat" approximation in absence of more precise data from manufacturer



Particle radii distributions applied

- **Gaussian distribution**
  - $f(a) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(a-\mu)^2}{2\sigma^2}\right)$
    - Location parameter μ
    - Spread parameter σ
  - Standard distribution for many physical phenomena
- $1/a^\lambda$ **distribution**
  - $f(a) = \frac{1}{a^\lambda}$
    - Spread parameter λ





From particle radius to signal size

- **Predicting a signal size distribution from a particle radius distribution**
  - We have a particle radius distribution function
  - We know how to find particle radius in terms of signal size (from Rayleigh law)
  - Thus, we simply plug in our formula for particle radius into our particle radius distribution function, and adjust the differential
  - This yields a signal size distribution function

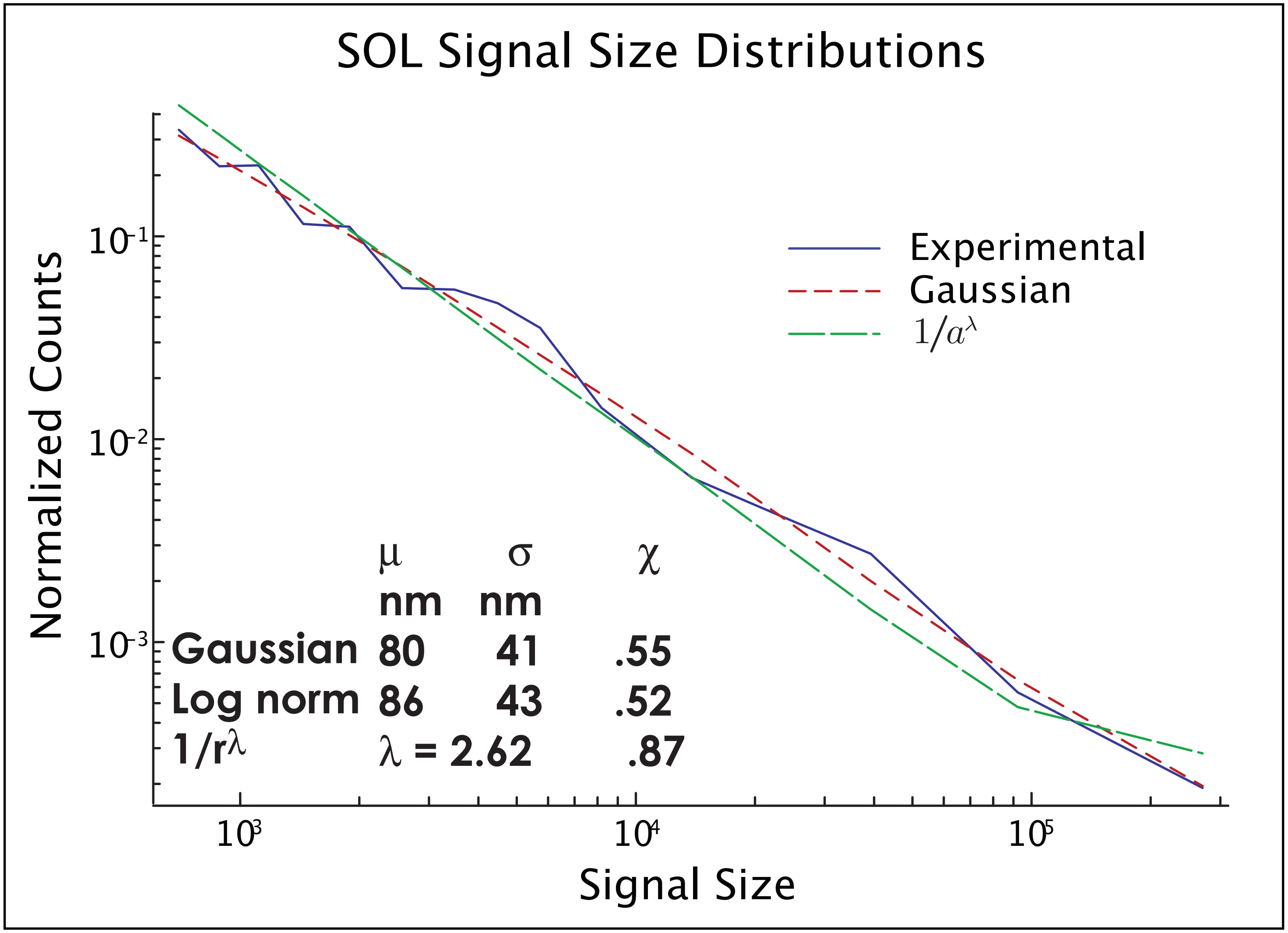
S: signal size, β: calibration factor, Γ: laser photon flux, $\overline{\Gamma}$: average laser photon flux

$$f(a) \longrightarrow a(S) = \sqrt[6]{\frac{S}{\beta}\frac{\overline{\Gamma}}{\Gamma}} \longrightarrow g(S) = \frac{f(a(S))}{dS/da} = \frac{1}{6S}\, f\left(\sqrt[6]{\frac{S}{\beta}\frac{\overline{\Gamma}}{\Gamma}}\right)\sqrt[6]{\frac{S}{\beta}\frac{\overline{\Gamma}}{\Gamma}}$$

f: distribution of particle radius a

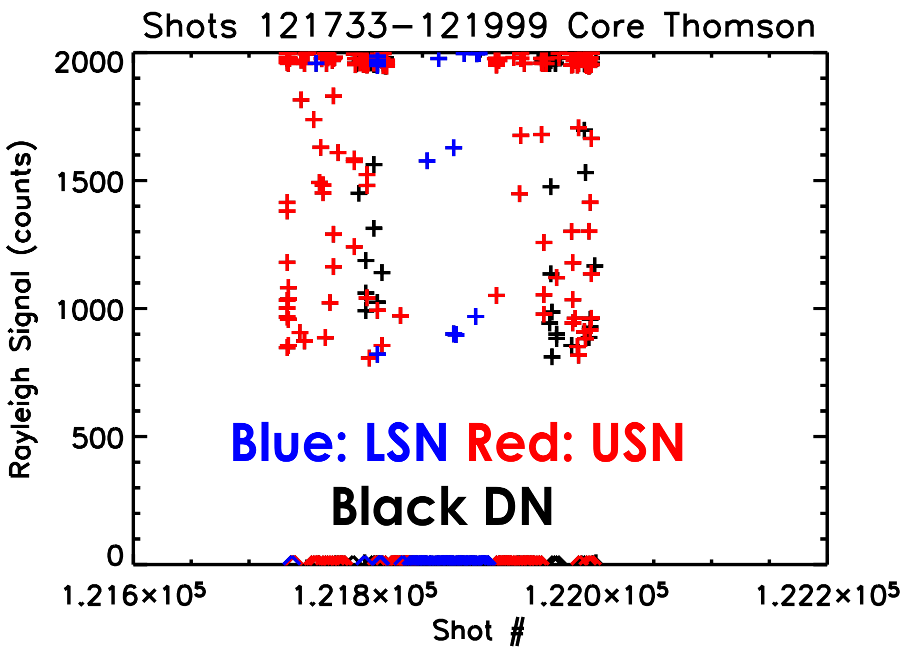
g: distribution of signal size

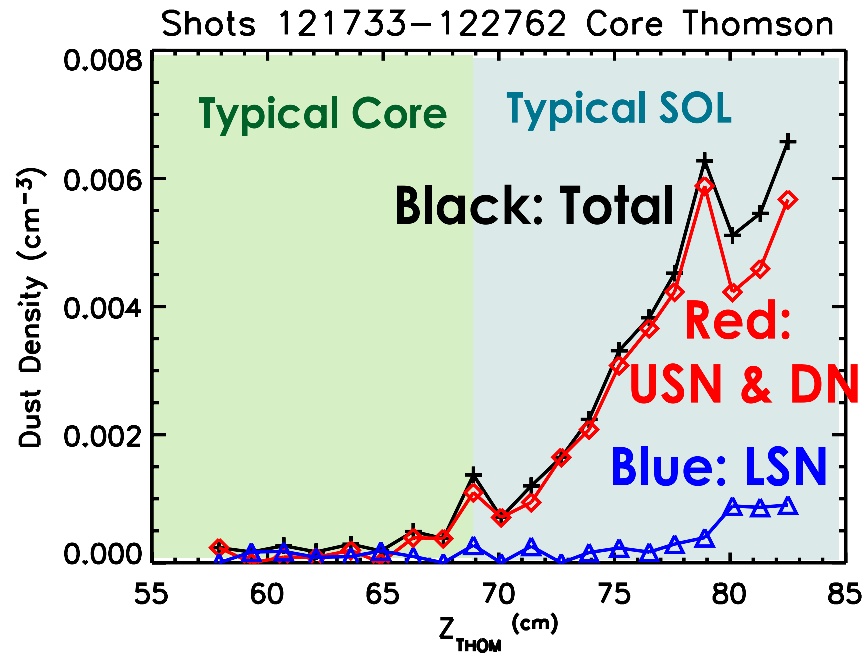
Comparison of model distributions to experimental distribution in SOL



Dust in Upper Region of SOL more Common in Upper Single and Double Null Operation

Dust in Upper SOL clearly
more common when upper null is active





Conclusions

- Dust has been observed in the SOL and divertor regions of DIII-D during normal plasma operations using the existing Thomson scattering system.
- In the SOL the density of dust particles is low, ~ 5 x 10^{-3} cm^{-3}
- The observed pulse height distribution suggests an average particle radius of ~ 80 nm. The existing dataset cannot distinguish between a normal or log normal size distribution
- The equivalent atomic carbon density in the SOL due to the dust is very low (~10^{11} m^{-3}) and probably does not constitute a significant source of carbon contamination.
- These particles seem to disappear in the SOL and do not reach the core plasma. However if they return to the wall they may constitute a tritium uptake problem.